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Simplified design of low speed electric permanent magnet generator for small wind power plant

M Irfan, E A Hakim, D Suhardi, N Kasan, M Effendy, A Faruq and M C Anam

Faculty of Engineering, Electrical Engineering Department, University of Muhammadiyah Malang,
246 Raya Tlogomas road, 65144 Malang, Indonesia

irfan_tsd@yahoo.com

Abstract. Wind power plant is one of the renewable energy where energy utilization is $\pm 3\text{-}5\%$ from potential existing of wind power. Wind power plant requires a generator to convert mechanical energy into electrical energy, mostly the generators available in the market is a kind of high speed induction generator which requires high rotational speed and an electricity to generate a magnetic field. While in wind power plant needs low speed generator and without initial electricity. Hence, a radial flux generator is designed in this project to have low speed rotation using permanent magnet type Neodymium Iron Boron (NdFeB). Finite Element Method (FEM) Magnet software is used for designing the generator model. Several modifications are applied to get optimum result by changing generator diameter, number of coils, the copper wire diameter, number of poles, and used slots. The simulation results obtained generator speed 500 rpm, the average series voltage is 185.44 Volt. Generator requires 18 cm diameter, number of turn for each coil is 55, diameter of the copper wire used is 0.6 mm, and number of poles is 8 pairs and 12 unit slots.

1. Introduction

The utilization of wind energy is the most renewable energy developed nowadays. With abounding wind potential in coastal areas of Indonesia, total capacity installed in wind energy conversion system is currently less than 800 kilowatts (kW). In the whole of Indonesia, five windmill units generator already built with each capacity of 80 kW. In 2007, followed by seven units with the same capacity has been built in four locations, each of three units in Selayar Island, North Sulawesi two units, and Nusa Penida, Bali, and Bangka Belitung one unit respectively. Referring to the national energy policy, the wind power plants expected to reach 250 megawatts (MW) by 2025 [1]. At the end of 2008, the electrification ratio in Indonesia is still 65.1%, while the lowest ratio (20% - 40%) in NTB, NTT, Southeast Sulawesi, Papua and West Irian Jaya areas. So that the government continues to strive increase the electrification ratio, especially in remote areas (areas that have not been electricity by the government) with utilizing renewable energy such as wind energy.

One of the important components in wind power station is a power generator, a device that converts wind turbine into electrical energy. The problem is, mostly electrical generators available in the market is high speed induction generator, that is requires a high speed between 1000 rpm – 1500 rpm, and also requires the initial electrical energy to create the magnetic field. While the thermal power station, which has a generator needs low rotation and without an initial electricity, this was due



to a wind speed average in Indonesia is 3.47 m/s and in Malang is 2.7 m/s [2]. With wind speeds are very small it is difficult to drive a high speed generator. Therefore, the objective in this project is to design an electric permanent magnet NdFeB generator that able to generate a large voltage and current with low-speed turning.

Application of wind power station has been successfully carried out previously by [2], precisely in the southern coastal district of Malang. However, the prototype made still using a modified car generator (dynamo), so that the voltage and the current generated is still very limited. The use of generator low speed has been successfully performed by [3] for lighting a street. In the axial generator comprising 9 coils was able to work at 560 rpm and a maximum output voltage of 30V.

Suhardi [4] has designed and built an electric generator low speed with 180 rpm. However, the electrical power generator is still very small; it is 25 Watt, with efficiency only 25%. Budiman *et al.* [5], has been created and tested an axial permanent magnet generator. Maximum electrical voltage produced at that time is 12V with a load current of 0.14A. However, the rotation speed of the generator is still quite high i.e. 1200 rpm. With permanent magnet material available on the market, Asy'ari *et al.* [6] has designed a low speed permanent magnet generator for wind power station. It was produced a permanent magnet generator design with a speed of 1000 rpm and a maximum voltage generated at 38V and 114 mA electric current.

An electric permanent magnet Neodymium Iron Boron permanent magnets ($\text{Nd}_2\text{Fe}_{14}\text{B}$) generator has designed in this work. The NdFeB permanent magnet is categorized as strong and rare magnet. Characteristics of the magnetic owned NdFeB better when compared with the other permanent magnet, such as Ferrite, Alnico and Samarium Cobalt. The maximum Energy Product (BHmax) can be produced between a 30 MGOe up to 52 MGOe, which reached 440 KJ/m³ [7]. Because it has a high magnetic characteristic, then the NdFeB magnet application has small dimensions and volume. In the other hand, these magnets can also replace the use of Samarium Cobalt magnets, in particular the use at a temperature is less than 80⁰ C [8].

Dilev *et al.* [9], has designed and built with the induction generator excitation system itself. Magnets used are NdFeB permanent magnets. However, the test has not been shown using certain electrical load, so that it was unknown how much the electric power can be generated. The use of NdFeB permanent magnet type generator for low speed has been successfully done by Alqodri *et al.* [10] in 2015 with a speed of 500 rpm, and 2V voltage generated. Thus it is critical to use the gear since it was built through hardware directly without design strategy. The researchers use CAD software to simplify designing of electrical generator. This tool unable to simulate and getting more result. Therefore, the challenges toward designing a high-performance and efficient electrical generator are necessary to examine with wind energy especially in rural area.

In this paper, the design and simulation of low speed permanent magnet generator has been demonstrated. Using Finite Element Method (FEM), the design of electrical permanent magnet NdFeB in this project referring the work by [11] and examined several steps they are determine the specifications of generator, followed by design of geometry that consists of components of stator and rotor, designing the air gap of stator and rotor, design of permanent magnets and coils used and simulate the model by running and plotting.

2. Initial design and geometry

This section describes an analytical design method of electric permanent magnet generator. The target is to determine an initial rotor and stator design, coil model, air gap model, while magnet type used is NdFeB. The generator designed in this project using FEM Magnet software basis.

Initialization and design geometry is a step to provide naming and determine of the material used on components contained in the generator and provides a measure of the thickness in each parts. By Initialization and geometry design, the generator can be simulated as well; it covers all component parts of the generator. The important components are consisting of geometry design of stator, rotor, magnet, coil, stator and rotor air gap, air box and shaft. Figure 1 shows initialized components of electric generator.

FEM software-based is a method used to solve the problem of complex electromagnetic field, so it can be solved by analytical models, especially in the part related to the nonlinear nature of the material. This method is basically a part of a cross-sectional discredited engine into areas or small volume called finite element or mesh. An initial mesh for stator, bottom rotor and magnet are set to 2 mm. While an initial mesh for top rotor and air gap are set to 1 mm and 0.5 mm respectively. Figure 2 shows a mesh determined for ¼ designs.

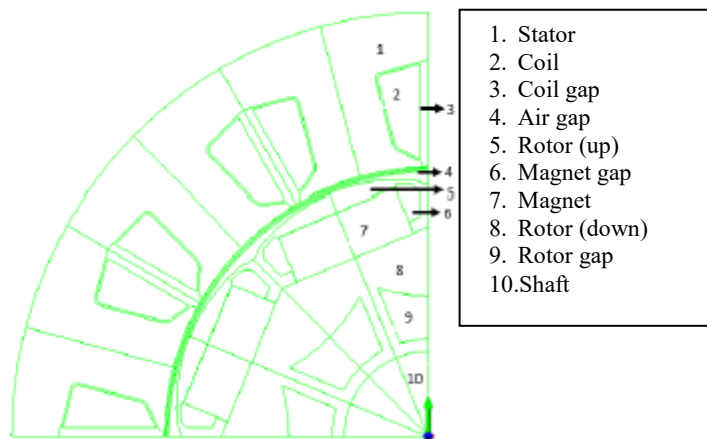


Figure 1. Initial components of electric generator.

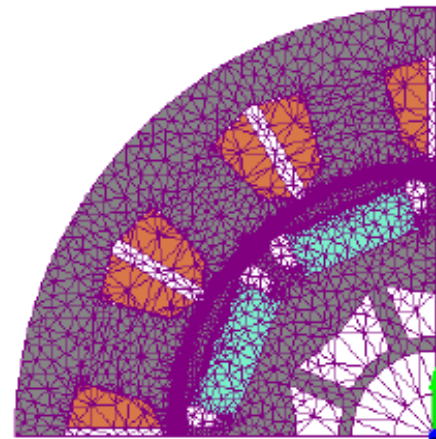


Figure 2. Mesh determined for ¼ designs.

To determine a mechanical degree and electrical degree of generator can be calculated by equation (1) and (2) respectively. While equation (3) to calculate a frequency.

$$\theta_M = \frac{360}{\text{Stator}} \times \text{pole} \quad (1)$$

$$\theta_E = \frac{\text{Pole}}{2} \times \theta_M \quad (2)$$

$$f = \frac{1}{T} \quad (3)$$

Where θ_M , θ_E , F and T are mechanical degree, electrical degree, frequency and amplitude of the generator respectively. In this work, ¼ design rotor rotated every 1 degree with time 0.1667 ms needed, so that to rotate 360 degrees it has 0.06 sec. Time rotation, rotation speed and energy coefficient can be formulated by equation (4), (5) and (6) respectively. Results of these analyses can be seen at table 1.

$$T_\theta = \frac{\theta_M}{\Sigma \text{ data sampling}} \quad (4)$$

$$\omega = 2 \cdot \pi \cdot f \quad (5)$$

$$K_E = \frac{V_{dc}}{\omega} \quad (6)$$

In this work, the electric generator has designed with detailed specifications. Table 1 shows the design variables of electrical permanent magnet generator.

Table 1. The variable designs of electrical permanent magnet generator.

Design variable	Initial value
Magnet poles	8 units
Magnet type	Neodymium Iron Boron Cylinder
Generator diameter	18 cm
Copper wire diameter	0.6 mm
Number of turns	25 pcs
Stator and rotor materials	USS Transformers stator 52-29 materials
Air gap (distance stator and rotor)	40 mm
Number of rotor	16 units
Number of stator	12 units
Stator air gap and rotor air gap	0.5 mm
Coil material	pure copper coil 5.77e7 Siemens/meter
Number of coils	55 units
Number of loops (full model)	660 windings
Total data sampling for ¼ designs	91 times

3. Simulation result and discussion

Figure 3 shows the result of flux linkage and voltage based on simulation respectively. Flux linkage is a flux that is connected or flowing from the rotor to the stator or reverse in. Flux linkage value is to determine the voltage produced by the generator. While each coil voltage is the voltage generated by each coil, in other words it is the voltage of each phase. The graph in figure 4 shows the result of voltage for each coil.

Series voltage is the voltage produced by the generator that is connected in series with load electric current. Thus the series voltage for each coil can be obtained from flux linkage each coil by multiply 4 for full 3600 model. From these data, inter-coil voltage can be obtained. Inter-coil voltage is the voltage between one phase with each other, in the other words it is the differencing voltage between phases. That is coil voltage-one deducted by coil voltage-two, and coil voltage-two deducted by coil voltage-three and then coil voltage-three deducted by coil voltage-one. Output voltage V_{dc} can be calculated by determining the average of inter-coil voltage. These graphs can be seen in figure 4 respectively. While simulation result with load-generator addressed in table 2.

Table 2. Load generator simulation result.

Parameters	Value	Units
Output voltage	185.44	Volt dc
Output electric-current	5	Ampere
Rotation speed	52.3	Rad/s
Frequency	8.33	Hz
Period/Time rotation ¼ design	0.12	Second
Energy coefficient	1.77	-
Torque	0.23	Nm
Mechanical degree	15	degree
Electrical degree	60	degree

Table 2 indicates load-generator simulation result with an output current 5 Amperes produced. The electric generator simulates with closed-loop circuit, electric current able to flow through the coil windings of generator. If 1 rad/s equal to 9.55 rpm, it can be seen that electric generator design with low speed 500 rpm. The electric generator design has been simulated to get maximum electric current

and time needed when it reaches maximum speeds, with customized load electric current. Figure 3 shows (a) the flux linkage of each coil and (b) the voltage of each coil. Figure 4 shows (a) the series voltage of each coil and (b) the inter-coil voltage and Vdc.

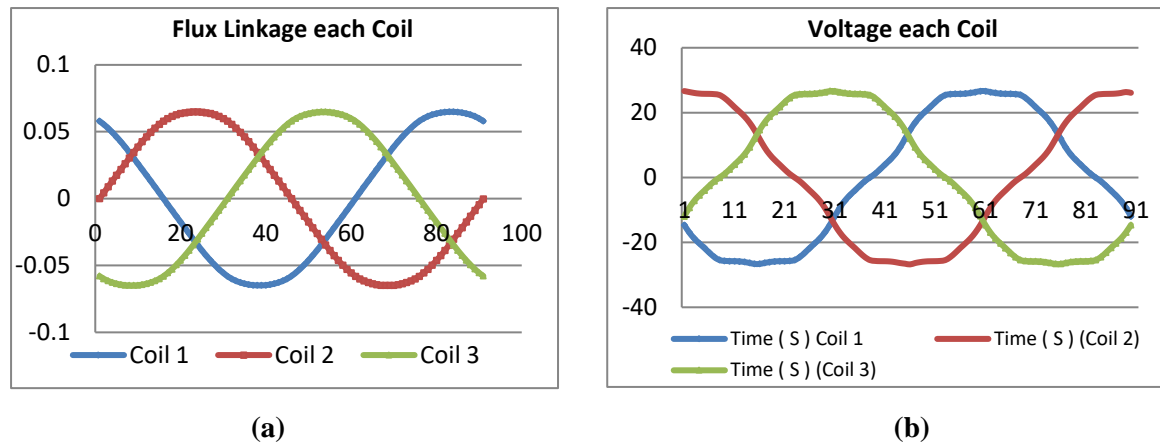


Figure 3. (a) Flux Linkage each Coil, (b) Voltage each Coil.

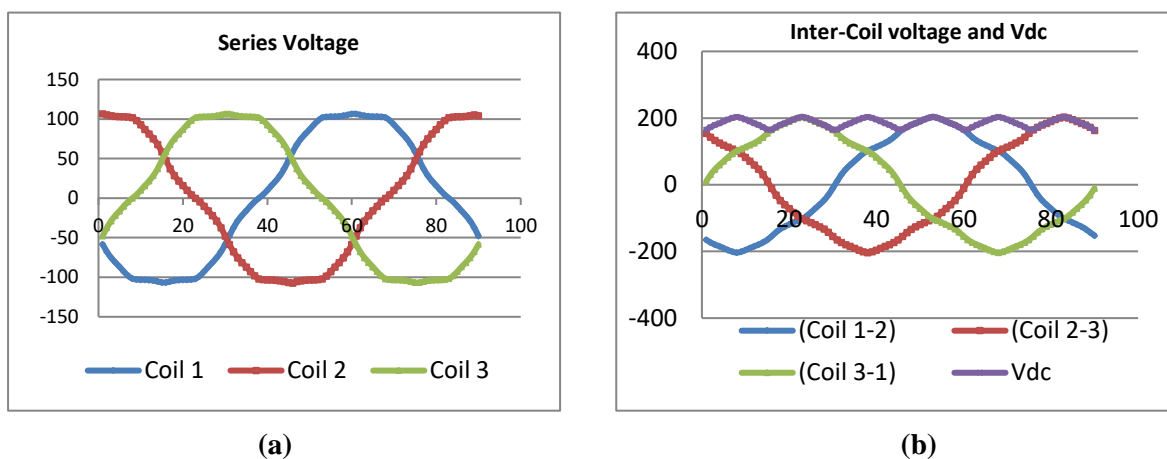


Figure 4. (a) Series Voltage each Coil, (b) Inter-Coil voltage and Vdc.

4. Conclusion

An analytical design and simulation presented in this work provided a low speed electric generator that can be played for small wind power plant. In terms of accuracy for simulation and generator construction, magnet type Neodymium Iron Boron (NdFeB) and other variables as mentioned (generator diameter, number of turns, poles of magnet) are considered. It is also observed that based on experimental design the air gap between rotor and motor is 1.5 mm. In this work, flux linkage each coil can also be simulated. These form can generate average voltage Vdc. Experimental design of magnet type materials and changing value of variables stated in this work can be as a future work in term of performance for electric generator. The effectiveness of different sample software is also of interest.

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